O(\(^5\)S) AND He(\(^3\)S) METASTABLE ATOMS STUDIED IN AN O\(_2\)-He MICROWAVE INDUCED PLASMA.

A-M DIAMY and J-C LEGRAND
Laboratoire de Chimie Générale, Université P. et M. CURIE
4 place Jussieu, 75230 Paris Cédex 05, France.

ABSTRACT.
O(\(^5\)S) metastable atoms production is studied in a gas-mixture microwave induced plasma (2450 MHz, 320 W) as a function of pressure (0.5 to 10 torrs) and oxygen dilution in helium (0 to 20 % O\(_2\)). A chemical mechanism is proposed and assuming a steady-state the quenching rate constant of O(\(^5\)S) by O\(_2\) is estimated to be \(1.4 \times 10^{-10}\) cm\(^3\)/molecule/s.

1. INTRODUCTION.
Metastable O(\(^5\)S) atom is an aeronomically important species but relatively few studies have been made with this state compared to O(\(^1\)D) and O(\(^1\)S) metastables. O(\(^3\)S) is also of great importance to achieve a quasistationary condition in some plasmas because of its slow evolution \([1]\). This paper reports on O(\(^3\)S) atom production in a microwave induced plasma (2450 MHz - 320 W) as a function of pressure (0.5 to 10 torrs) and oxygen dilution in helium (0 to 20 % O\(_2\)).

2. EXPERIMENTAL.
O(\(^5\)S) and He(\(^3\)S) densities are measured by observing the absorption of 7771.96 Å and 3888.65 Å lines respectively. For line absorption measurements two identical discharges are used as shown in figure 1. Electron temperature and electron concentration are also determined by double electrostatic probes. From current-potential characteristics temperature is obtained by the equivalent resistance method and concentration by the theory described by SU and Kiel \([2]\).
All the measurements are performed at the exit of the resonant cavity (GOUDMAN type).
The discharge temperature required for calculations was estimated at 600 K.

3. RESULTS AND DISCUSSION.
The results obtained for metastable concentration are shown in figures 2, 3 and 4.
Maximum O(\(^5\)S) concentration is observed with molecular oxygen concentration and pressure increases while He(\(^3\)S) concentration decreases continuously.
Figures 5 and 6 show the results concerning electron temperature and electron concentration. The values obtained are in good agreement with Brasse and Maessen results for helium [3].

According to the results obtained the following mechanism for $O(5S)$ production and destruction is proposed:

\[ O_2 + e \rightarrow \begin{cases} 0(5P) + O + e \\ 0(5S) + O + e \end{cases} \]  
(1a)

\[ O + e \rightarrow \begin{cases} 0(5P) + e \\ 0(5S) + e \end{cases} \]  
(1b)

\[ He(3S) + O_2 \rightarrow \begin{cases} He + O(5P) + e \\ He + O(5S) + e \end{cases} \]  
(2a)

\[ O(5P) \rightarrow O(5S) + h\nu(7773 \text{ Å}) \]  
(2b)

\[ O(5S) + O_2 \rightarrow \text{products} \]  
(3a)

\[ He(3S) + O_2 \rightarrow \text{products} \]  
(3b)

\[ O(5S) + \text{walls} \rightarrow \text{products} \]  
(4a)

\[ O(5S) \rightarrow O(3P) + h\nu(1356 \text{ Å}) \]  
(4b)

$O(5S)$ Formation: Under our conditions, the major contributions to $O(5S)$ formation are dissociation of molecular oxygen and excitation of atomic oxygen by electron impact (reactions 1 and 2). Radiative cascade from higher excited states of atomic oxygen (specially $O(5P)$) is another means of populating the $O(5S)$ state (reaction 4). Dissociative excitation is an important exit channel of $He(3S)$ quenching by molecular oxygen [4] and this process can contribute to $O(5S)$ formation (reaction 3).

$O(5S)$ Destruction: Destruction of $O(5S)$ takes place principally by collision and diffusion to the walls (reaction 5 and 6). As polyatomic molecules are generally much more efficient at quenching electronic excitation than monatomic species, collisions with $O_2$ are only considered. Reaction 7 can be neglected in comparison with reactions 5 and 6.

Determination of the quenching rate constant $k_5$: If we assume a steady state for $O(5S)$ and $O(5P)$, from the above mechanism, the following expression is obtained:

\[ k_5 [O_2] = F - D/\Lambda^2 \]

where:

\[ F = \{k_1 [O_2] [e] + k_2 [O][e] + (k_{3a} + k_{3b}) [He(3S)] [O_2] \} / [O(5S)] \]

$\Lambda$ is the characteristic diffusion length given by $R/2,405$;

$R$ is the radius of the discharge tube.

Assuming a Maxwellian distribution for electrons, the constants $k_1$ and $k_2$ are determined from the total cross section including cascading relative to these processes [5, 6].

The concentration of atomic oxygen is estimated to be 10% of initial concentration of molecular oxygen [7].

$D$ is the diffusion coefficient of $O(5S)$ in the gas mixture given by [8]:

\[ 1/D = x_1/D_1 + x_2/D_2 \]
$x_1$ is the mole fraction of $O_2$ and He and $D_1$ the binary diffusion coefficient of $O(3P)$ in $O_2$ and He. The collision parameters of $O(3P)$ required to calculate diffusion coefficients are not known. Consequently to plot the linear relation $(F - D/A^2) = f(O_2)$, $D_1$ and $D_2$ are considered as optimization parameters. The slope of this graph gives the following value for $k_5$:

$$k_5 = [1.4 \pm 0.4] \times 10^{-10} \text{ cm}^3 \text{ molecule}^{-1} \text{ s}^{-1}$$

For $D_1$ and $D_2$, the values obtained are:

$$D_1 = 1290 \text{ cm}^2 \text{ s}^{-1}$$
$$D_2 = 4030 \text{ cm}^2 \text{ s}^{-1}$$

These values are of the same order of magnitude as the values computed for $(O \ 3S)$ under the same conditions using collisions parameters determined by ZIPF [9].

REFERENCES.
[Figure 4]

[Figure 5]
Fig 6

Fig 7